TIME FREQUENCY ANALYSIS AND SPATIAL FILTERING IN THE EVALUATION OF BETA ERS AFTER FINGER MOVEMENT

A.M. Bianchi[1], G. Foffani[1], S. Cerutti[1], C. Babiloni[2,3], P.M. Rossini[4], F. Carducci[2,3], F. Babiloni[2], F. Cincotti[5]

[1]Dipartimento di Bioingegneria, Politecnico di Milano, Italy
[2]Dipartimento di Fisiologia Umana e Farmacologia, Università "La Sapienza", Roma, Italy.
[3]AFaR IRCCS - Dipartimento di Neurologia, Osp. FBF Isola Tiberina, Roma, Italy.
[4]IRCCS "S. Giovanni di Dio", Via Pilastroni 4, Brescia, Italy.
[5]IRCCS Fondazione Santa Lucia, via Ardeatina 306, Roma, Italy

Abstract-**Different methods are compared for the evaluation of the event related synchronization (ERS) in the beta rhythm corresponding to finger movements. In addition to the standard procedure usually employed, the realistic Surface Laplacian (SL) is here introduced to improve the spatial localization of the phenomenon, while a Wavelet Packet (WP) decomposition approach is intended to better detect the time dependent characteristics. The parameters of interest (ERS amplitude and latency) were statistically analyzed through Analysis of Variance (ANOVA) and Scheffe's test. The WP filtering results are well comparable with the traditional filtering procedure. On the other hand, the realistic SL considerably improves the spatial localization and the consistency of the estimation (decreased variance) of the ERS amplitude.**

Keywords- **Event Related Desynchronization/Synchronization, Surface Laplacian, Wavelet Packets**

I. INTRODUCTION

The event related modifications induced in the EEG signal provide fundamental information on the neural processes involved. In particular, the study of the event related desynchronization/synchronization (ERD/ERS) is now a widely diffused tool for physiological and clinical studies.

The power changes that characterize the ERD/ERS are indeed time-variant phenomena. On the other hand, the EEG spatial information is known to be corrupted by the blurring effect due to the tissues interposed between the sources and the recording sites.

The actual possibility of multichannel EEG recording (up to 128 electrodes) and the continuous enhancement of computational power make the application of advanced procedures reliable to improve time-frequency resolution and spatial localization.

Various methods are proposed in the literature (see [1]) to characterize the ERD/ERS both in time-frequency and in space. In this paper, the standard band-filtering approach is compared with a Wavelet Packet (WP) analysis, and spatial resolution is improved through the calculation of the realistic Surface Laplacian (SL). In order to better characterize the features of the above methods the relevant parameters (ERS amplitude and latency) are statistically analyzed for a complete comparison of their different combinations. The presented results are restricted to the beta ERS phenomenon that is temporally and spatially well localized.

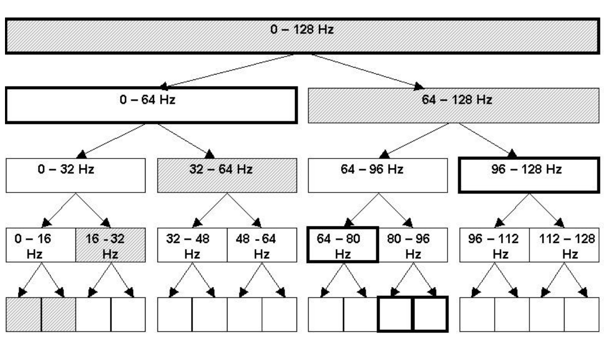

Fig. 1 Scheme of the Wavelet Packet decomposition. The gray boxes represent the traditional wavelet decomposition as a particular case of WP, while the bold boxes represent an alternative possible decomposition.

II. METHODOLOGY

A. Time-frequency analysis: Wavelet Transform

The Wavelet Transform performs the analysis of a signal *x(t)* according to wavelet functions that can be defined as:

$$h_{a,t} = \left(1/\sqrt{a}\right)h\left((t-t)/a\right).$$

Each wavelet is obtained by scaling (contracting or dilating) and shifting in time a wavelet prototype (or *mother wavelet*) *h(t).*

In the discrete time case the dilation factor *a* and the shifting factor *t* vary according to the following dyadic rule:

$$a = a_0^j \qquad t = ka_0^j T$$

where $a_0 = 2$, j and k are integers and T is the sampling interval of the digital signal.

The analysis results in a set of wavelet coefficients, which indicate how close the signal is to a particular basis function in different time intervals and in different frequency scales.

$$c_{k,j} = \int x(t) h_{j,k}^*(t) dt$$

Changes in the j parameter determine the dilation of the wavelet, and then the scale through which the signal is viewed, while changes in k parameter determine the time position of the wavelet with respect to the signal. The resulting analysis has the fundamental characteristic of being multiscale. In fact, for large values of j we can look at very small details in the signal (high time resolution and low frequency resolution), and for small values of j we look at the signal through a larger scale (low time resolution and high frequency resolution). The discretization of the frequency domain is imposed by the sample frequency and by the transformation algorithm. For example, when the signal is sampled at 256 Hz, and the analysis is performed up to the 5th level, the WT decomposition will result in the following frequency bands: 64-128 Hz; 32-64 Hz; 16-32 Hz; 8-16 Hz; 4-8 Hz; 0-4 Hz, which cover the whole frequency axis.

When a different decomposition is needed, a more general analysis can be achieved through *Wavelet Packets* (WP) [2,

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25OCT2001	N/A	-

Title and Subtitle Time Frequency Analysis and Spatial Filtering in the Evaluation of BETA ERS After Finger Movement	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Dipartimento di Bioingegneria, Politecnico di Milano, Italy	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from the 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 4	

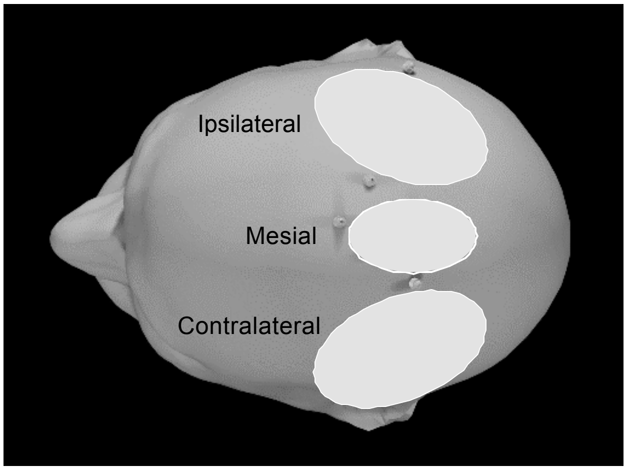

Fig.2 Localization on the head of the 19 examined electrodes. The ROIs have been evidenced

3]. Fig.1 shows the general decomposition achieved through WP transform. The gray boxes indicate the more traditional WT decomposition as a particular case of the WP. Different decompositions of the frequency axis can be achieved through different choices, for example the one marked with bold boxes.

B. Spatial filtering: Realistic Surface Laplacian

The realistic Surface Laplacian (SL) performs the estimation of the Laplacian operator over a realistic scalp surface model, constructed from superimposed MRI sections. It includes a tensorial formulation ([4]), which uses a 3D analytical spline function ([5]) to model the potential distribution. Such tensorial formulation allows the calculation of the SL of the potential using a non-orthogonal curvilinear coordinate system on the subject's scalp surface model ([6]). This procedure can be improved by approximation rather than interpolation of the potential distribution (λ□□ correction; [7], [6]).

III. EXPERIMENTAL PROTOCOL

A. Data acquisition and pre-processing

Movement-related scalp Potentials were recorded (128 channels; 0.1-100 Hz bandpass; linked-earlobe electric reference) during the preparation and execution of simple self-paced right middle finger extensions (6-20 sec inter-movement interval), from eight normal volunteers who gave their written informed consent before the experiments (the general procedures were approved by the local institutional ethics committee).

The rectified electromyogram (EMG, 1-100 Hz bandpass) of the operating muscle (right extensor digitorum) was recorded to fix the onset of the muscle response, while the registration of the electrooculogram (0.1-100 Hz bandpass) served to reject off-line the EEG trials corrupted by blinking and eye movement artifacts. All data were acquired at 256 Hz sampling rate. The acquisition time was from 4 sec before to 4 sec after the electromyographic onset. The subjects executed 3 series of 30 trials separated by 5-10 min intervals.

Sixty-four T1-weighted sagittal MRIs were acquired from each subject. The MRI acquisition was performed with 30 ms repetition time, 5 ms echo time, and 3 mm slice thickness without gap.

The MRIs allowed a realistic reconstruction of the shape of the subjects' scalp by segmentation of the voxels belonging to the scalp-air interface. The scalp modeling was obtained by interpolating 577 points of scalp MRI contours with a 2-D thin plate spline function. The realistic SL was then computed.

Nineteen channels in the central region of the scalp provided data for the rest of the analysis, as shown in Fig.2.

B. Data analysis

Power spectrum analysis of the artifact-free potential and SL-transformed data was performed with the Welch technique (Hanning windowing function) at "pre-movement" (from -3.5 s to -2.5 s with respect to EMG onset) and "post-movement" (from +1 s to +2 s) periods.

Beta ERS was computed for a band in which EEG data presented consistent "rest-task" differences in individual power spectra. The band components were extracted by means of a FIR narrow bandpass filter (zero phase, 2 Hz bandpass; 0.5 s impulse response length) as a reference method.

The WP method was also applied, performing a 6th level tree decomposition (2 Hz band width, from 256 Hz sampling rate). The mother wavelet used was the Coiflet of order 3 ([8]), which is compactly supported and near from symmetry. The signals in the frequency bands of interest were then reconstructed from WP coefficients. Note that according to the filter bank interpretation of Wavelet analysis, the WP approach can be view as a special band-pass filtering.

To estimate the beta band instant power, samples of filtered raw and SL-transformed EEG time-series were squared and averaged across trials, for both FIR and WP approaches.

TABLE 1
MEANS AND SD OVER SUBJECTS OF THE ERS PEAK AMPLITUDES AND LATENCIES THE VALUES ARE CALCULATED WITH THE DIFFERENT ANALYSIS METHODS (LAP/RAW, FIR/WP) FOR THE THREE ROIS (CONTRA, IPSI, MESIAL)

		FIR						WP					
		Lap			Raw			Lap			Raw		
		contra	ipsi	mesial	contra	ipsi	mesial	contra	ipsi	mesial	contra	ipsi	mesial
Amplitudes (%)	MEAN	252	178	205	88	79	94	225	163	195	99	97	101
	(SD)	(89)	(148)	(95)	(54)	(38)	(42)	(125)	(85)	(111)	(80)	(43)	(47)
Latencies (ms)	MEAN	1464	1313	1328	1344	1375	1359	1438	1438	1406	1438	1446	1438
	(SD)	(238)	(320)	(359)	(416)	(327)	(363)	(149)	(149)	(297)	(259)	(175)	(241)

Beta ERS responses were then computed using a 1 s long reference time window ranging from 3 s to 2s before EMG onset and were expressed, for each electrode site, as a percent increase/decrease of instant power with respect to the mean power computed across the reference window.

The 19 electrodes were grouped into three regions of interest (ROIs) placed in the contralateral, ipsilateral to the movement and mesial scalp regions (see Fig.2).

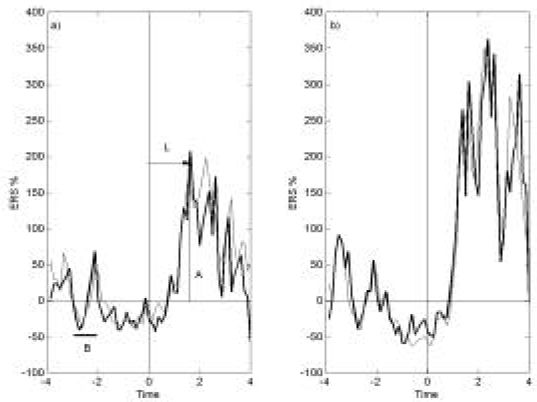

Fig.3 ERS % evaluated from a) the raw signal and b) the SL. The thin line represents FIR filtering, while the dark one is WP filtering. The baseline B is marked, as well as the latency L and the amplitude A.

For each ROI, a maximally responsive channel was selected. The beta ERS peak latencies and amplitudes were measured for these channels.

Fig. 3 shows the controlateral ERS on a single electrode from one subject, calculated with the four methods, evidencing all the parameters.

C. Statistical analysis

The aim of the statistical analysis was to evaluate the influence of particular choices of spatial filtering and processing methods, on the computation of ERS amplitude and latency parameters. Hence, two different three-way Analysis of Variance (ANOVA) were performed, using either amplitude or latency of the ERS peak computed from potential and SL-transformed data as dependent variables.

The main factors of the ANOVA were: (i) the method used for ERS spectral computation (METH with two levels; FIR and wavelet), (ii) the type of spatial filter operator used (SPAT, with two levels; potential and SL), and (iii) the appropriate scalp region where the ERS amplitude/latency was evaluated (ROI, with three levels; contra, ipsi and mesial).

The post hoc analysis was performed with the Scheffe's test at the 5% level of significance. The Greenhouse-Gasser correction was applied to the ANOVA results due to the violation of sphericity assumption ([9]).

IV. RESULTS AND DISCUSSION

A. Beta ERS amplitude data analysis

The results of the ERS peak amplitude estimation are presented in Tab.1.

The ANOVA (see Tab.2) demonstrated that the use of SL significantly decreases the variance of the amplitude of beta ERS (SPAT main factor, $F = 27.42$, $p = 0.001$). Of note, the type of spectral estimation used for the EEG data does not decrease the error variance of the ERS beta estimation (METH main factor, $F = 0.329$, $p = 0.847$). The same holds for the main factor ROI, that does not decrease the error variance per se (ROI main factor, $F = 0.692$, $p = 0.517$). Of interest, the only significant interaction involved the factors METH x SPAT ($F = 5.667$, $p < 0.049$).

Statistical analysis (Scheffe's test) revealed that the computation of the SL transformation gives ERS beta values higher than the ones offered by the evaluation of raw EEG data. This was observed both applying the FIR method ($p = 0.0001$ for the Contralateral ROI, $p = 0.017$ for the Ipsilateral ROI and $p = 0.006$ for the Mesial ROI) and the WP method ($p = 0.002$ for the Contralateral ROI and $p = 0.017$ for the Mesial ROI).

As a difference with respect to the FIR method, with the WP method the amplitude of the ERS beta does not differ in the Ipsilateral areas for the SL and raw EEG data ($p = 0.22$).

Scheffe's test suggested that for the SL-transformed and raw EEG data the differences between the amplitude of the ERS beta obtained by using the two computational methods (FIR and WP) are not significant in all the ROI considered (contralateral, ipsilateral and mesial) with $p = 0.99$.

Fig.4 shows the ERS peak amplitude cortical maps, which permit a comparison of the different analysis methods from a spatial point of view.

B. Beta ERS latency analysis

The results of the ERS peak latency estimation are presented in Tab.2.

The ANOVA performed on the data relative to the latency of the beta ERS returned no significant decrease of the error variance due to the main factors employed in the analysis, namely METH ($F = 1.13$, $p = 0.322$), SPAT ($F = 0.05$, $p = 0.94$) and ROI ($F = 0.40$, $p = 0.67$). It can be concluded that such factors do not affect the evaluation of latency of beta ERS. Hence, similar latency values can be obtained by using both different kind of spectral methods as well as SL and raw EEG data, on all the ROI analyzed.

TABLE 2
ANOVA RESULTS ON THE ERS PEAK AMPLITUDES AND LATENCIES

	Amplitude		Latency	
	F	p	F	p
METH	0.329	0.847	1.134	0.322
SPAT	27.42	0.001	0.006	0.942
ROI	0.692	0.517	0.404	0.675
METH × SPAT	5.667	0.049	0.074	0.794
METH × ROI	0.086	0.918	0.371	0.696
SPAT × ROI	1.086	0.364	0.456	0.643
METH × SPAT × ROI	0.179	0.838	1.339	0.294

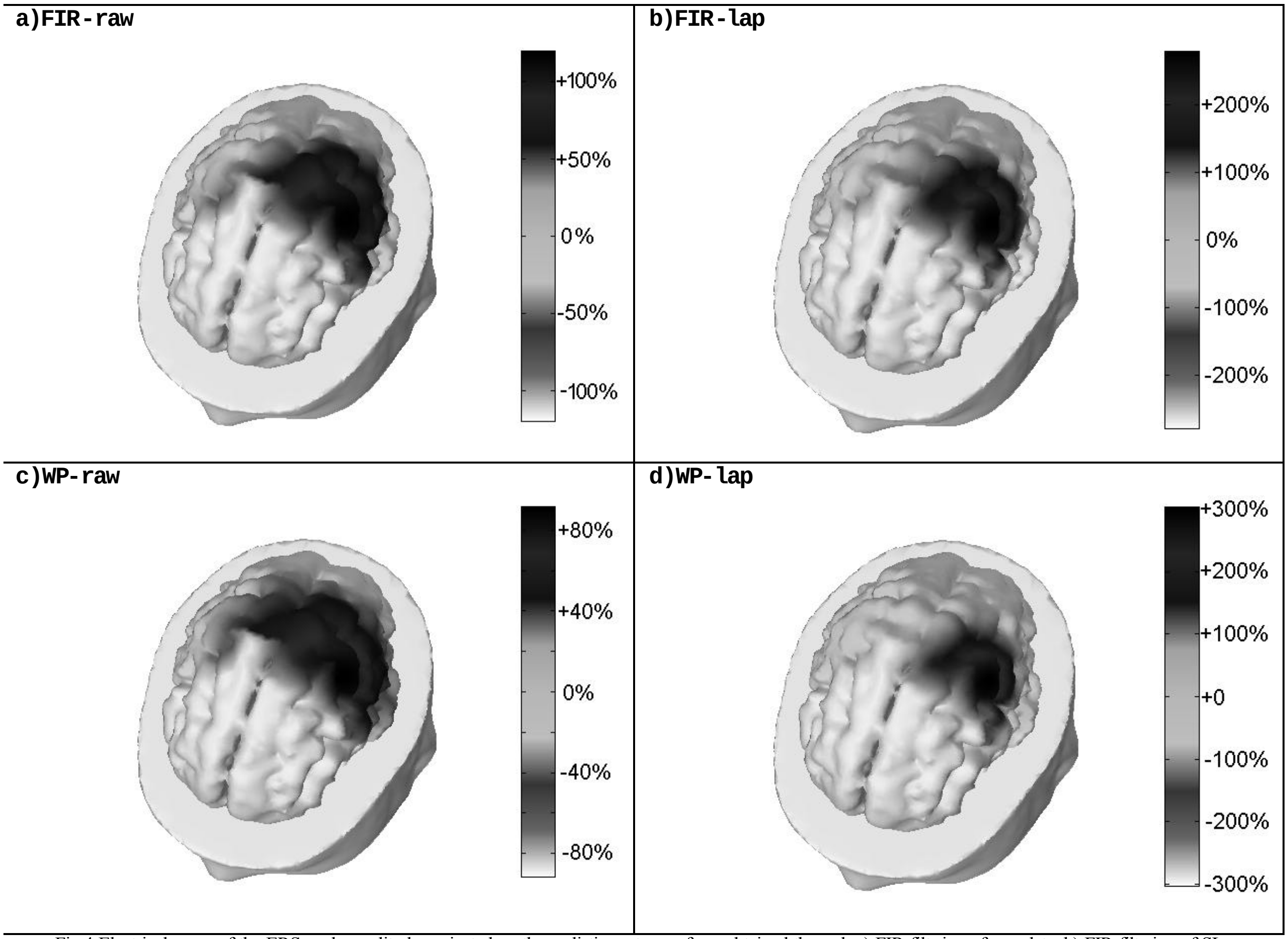

Fig.4 Electrical maps of the ERS peak amplitude projected on the realistic cortex surface, obtained through a) FIR filtering of raw data, b) FIR filtering of SL, c) WP filtering of raw data and d) WP filtering of SL

V. CONCLUSIONS

The obtained results provide useful information on the methods proposed in the paper and on their capability in evaluating the parameters of interest.

On one hand the WP filtering results are well comparable with the traditional filtering procedure. On the other, the realistic SL considerably improves the spatial localization and the consistency of the estimation (decreased variance) of the ERS amplitude, while the latency estimation seems to be independent on the method.

Thus the SL should be strongly recommended in multichannel protocols when the spatial description is of primary interest.

The WP filtering capability of a multiresolution time-scale representation of the signal was not investigated in this paper; it gives different point of view to the problem and will be the subject of a future study.

VI. REFERENCES

[1] Pfurtscheller, G. Lopes da Silva, F.H. Event related EEG/MEG synchronization and desynchronization: basic principles. Clin. Neurophysiol. 110 (1999) 1842-1857

[2] Mallat, S. A theory of multiresolution signal decomposition: the wavelet representation. IEEE Pattern Anal. and Machine Intell., vol.11, no. 7, pp 674-693, 1989

[3] Wickerhauser, M.V., INRIA lectures on wavelet packet algorithms. Proceedings ondelettes et paquets d'ondes. 17-21 june, Rocquencourt France, pp. 31-99, 1991

[4] Spiegel, M. Theory and problems of vector analysis and an introduction to tensor analysis. Mc Graw Hill, New York, 1978

[5] Duchon, J. Interpolation des fonctions de deux variables suivant le principe de la flexion des plaques minces. R.A.I.R.O. Anal. Num., 1976, 10: 5-12.

[6]Babiloni, F., Babiloni, C., Carducci, F., Fattorini, L., Onorati, P. and Urbano, A. Spline Laplacian estimate of EEG potentials over a realistic magnetic resonance-constructed scalp surface model. Electroenceph. clin. Neurophysiol., 1996, 98(4): 363-373.

[7] Harder, R. and Desmarais, R. Interpolation using surface splines. J. Aircraft, 1972, 9: 189-191.

[8]Maceri, B., Magnone, S., Bianchi, A., Cerutti, S. Studio della decomposizione wavelet dei segnali: applicazione al segnale elettroencefalografico. Politecnico di Milano, AA 1997-1998

[9] Zar, H. Biostatistical Analysis. Prentice Hall, New York, 1984

ADDRESS FOR COMMUNICATIONS
annamaria.bianchi@polimi.it